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POSSIBILITIES FOR DETECTION OF THE CHANGE OF BIODEGRADABILITY OF WASTEWATER BY DIELECTRIC CONSTANT MEASUREMENTS

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ABSTRACT

Nowadays, the development of rapid and non-destructive measurement methods have high importance. The dielectric measurement is a promising technique to detect the chemical and physicho-chemical change of different materials. The dielectric behavior of pure water is widely investigated for decades, but there is very few information available related to the dielectric parameters of wastewater. Our study aims to investigate the applicability of dielectric measurements for the detection of the change of biodegradability of wastewater. In the experiments the change of organic matter solubility and biodegradability of sugar beet processing wastewater, meat processing wastewater, dairy industry wastewater and municipal wastewater was examined. Our results show that dielectric constant - measured at the frequency of 2400 MHz - has a strong linear correlation with the soluble chemical oxygen demand (SCOD), which makes possible the fast detection of disintegration efficiency of different wastewater and sludge treatment processes, or the organic matter removal efficiency of wastewater purification technologies. Furthermore, our results verified that the change of aerobic biodegradability (expressed in BOD_5/SCOD ratio) show also good linear correlation with the dielectric constant. These preliminary results enable to develop a dielectric behavior based detection method for the estimation of the efficiency of wastewater treatment processes.

Keywords: dielectric measurements, wastewater, biodegradability, solubility

1. INTRODUCTION

A dielectric material is a non-conducting material which stores electrical charges. In order to characterize how a certain dielectric material behaves when placed in an electromagnetic field, it is necessary to know the so-called dielectric properties of it. These properties can offer information about the occurring interaction between the material and the electromagnetic field itself [1]. Dielectric behavior of materials is influenced by the frequency, temperature and the physicochemical structure of the materials.
One of the most important properties is the relative permittivity, which primarily describes those features that affect the reflection of electromagnetic waves on the boundary surface of the material, and the energetic loss that happens when the wave is absorbed inside the material. The relative complex permittivity can be calculated as follows:

$$\varepsilon = \varepsilon' - j\varepsilon" \quad (1)$$

In the equation ε_r' represents the dielectric constant, $\varepsilon_r^{"}$ is the dielectric loss factor, and j is the imaginary unit.
The dielectric constant describes the energy-absorbing ability of a given dielectric material when put in an electromagnetic field, and affects the phase of the wave that goes inside and/or through the material. The dielectric constant can be calculated as the product of free space permittivity and the relative permittivity:

$$\varepsilon' = \varepsilon_0 \cdot \varepsilon_r' \quad (2)$$

The dielectric loss factor (ε") is a measure of the loss of energy in a dielectric material due to conduction, slow polarization currents, heat-transformation and other dissipative phenomena.

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As mentioned earlier, a dielectric material is a solid, liquid or gaseous material that behaves as a non-conductor in terms of electricity, i.e. contains no free charges. The bound charges in a material can be presented in two different orientations: sphere-symmetric and dipole-like. In a sphere-symmetric orientation, the electric field only occurs inside the atoms/molecules, but not in the interatomic/intermolecular field. During dipole-orientation, the center point of the two different charges does not overlap, therefore the electric field is presented between the molecules too – however, it is not lasting, i.e. the undisposed molecular diploes cancels each other's electric field out.
The field-strength of the electric field that comes off inside the material is weaker than the strength of the electromagnetic field that covers it, because the direction of the diploe's electric field inside the material is the exact opposite than that of the covering electromagnetic field. Therefore a dielectric material weakens the field-strength of the electromagnetic field that it is placed in, according to Eq2.
Since at a given frequency, most of the dielectric parameters depend on the temperature and physicochemical structure of the material, the measurement of these properties can be used to detect certain physical and chemical changes inside the material [2].
Applicability of dielectric measurement covers lot of different materials: starting from ingredients of food (and food itself) in order to detect change in their structure, it can also be used in wastewater treatment as an example. In a 2012 study it has been shown however that dielectric properties vary significantly with moisture/solid-content ratio and with frequency, therefore for proper result, these factors should be taken into account. [3]
Dielectric measurements can be applied in various industries as well – in foresting they are used to identify how much moisture is contained in wood and paper, while in mining, it is used to analyze the content of oil. [4]. It can be also used to estimate the permittivity of coal and limestone as well [5]. The dielectric parameters govern the microwave energy absorption into the materials. If materials have a dielectric loss factor below 0.01 high energy needed for heating. In general, the high frequency electromagnetic filed is suitable for lower penetration depth, therefore industry scale microwave equipment operate at lower frequency (915 MHz) to achieve higher penetration depth and higher energy absorption in continuously flow operation and/or solid materials with higher geometric dimensions (above 10 cm). It is verified, that in capillary-porous structured materials, such as food and raw materials of food processing, higher energy in needed to evaporate the bounded water than that of needed for free water in capillaries. The porosity of granulated materials and particles, furthermore the fiber orientation has also effect on the heating efficiency [6].
Dielectric measurements are suitable to detect enzymatic and chemical reactions, as well. Depending on the frequency range of dielectric parameters, the non-enzymatic browning reactions [7] and organic matter removal efficiencies of wastewater treatment processes [8] are also detectable.
Our research focused on the investigation of the correlation between the change of biodegradability indicators of wastewater and the dielectric parameters measured at the frequency range of 200-2400 MHz. The main aim of the research is to develop rapid and non-destructive measurement technique to detect the change of organic matter solubilization, disintegration degree and biodegradability which is suitable to estimate the efficiency of different pre-treatment process before wastewater and sludge utilization technologies.

2. MATERIALS AND METHODS

For the dielectric measurements municipal wastewater (MUWW), dairy industry wastewater (DWW), meat processing wastewater (MPWW) and sugar beet processing wastewater (SCWW) was used.
The wastewater samples were pre-treated by microwave irradiation at power intensity of 1.5-5 W/mL, for irradiation time of 5-30 minutes to achieve higher organic matter solubility and biodegradability.

The soluble chemical oxygen demand (SCOD) was determined by colorimetric method (Hanna MR/HR COD cuvettes, PC Checkit photometer, after 15 minutes thermodigestion at 180°C), after centrifugation (RCF=6000 for 10 minutes) and filtration (0.45 μm pore sized PTFE disc filter).
The 5 days biochemical oxygen demand (BOD5) was measured by respirometric method in BOD Oxidirect unit at 20°C using BOD Seed as inoculum. For the dielectric measurements a ZVL3 vector network analyser (Rohde&Schwarz) equipped by a DAK3.5 (Speag) dielectric sensor was used in a frequency range of 200 -2400 MHz [8].

3. RESULTS AND DISCUSSION

The aim of our research was to investigate the correlation between the dielectric parameters and biodegradability indicators. The solubility of organic matters expressed in SCOD is an indirect parameter to quantify the availability of organic substrate for microbial degradation.
In our experiments the change of SCOD was induced by treatment of microwave irradiation. The dielectric measurements were carried out for samples which are cooled to temperature of 20°C. Our results show that microwave irradiation was suitable to increase the organic matter solubility.
Results of dielectric measurements show that the dielectric constant at the frequency of 2400 MHz has a good linear correlation with the SCOD (Figure 1).

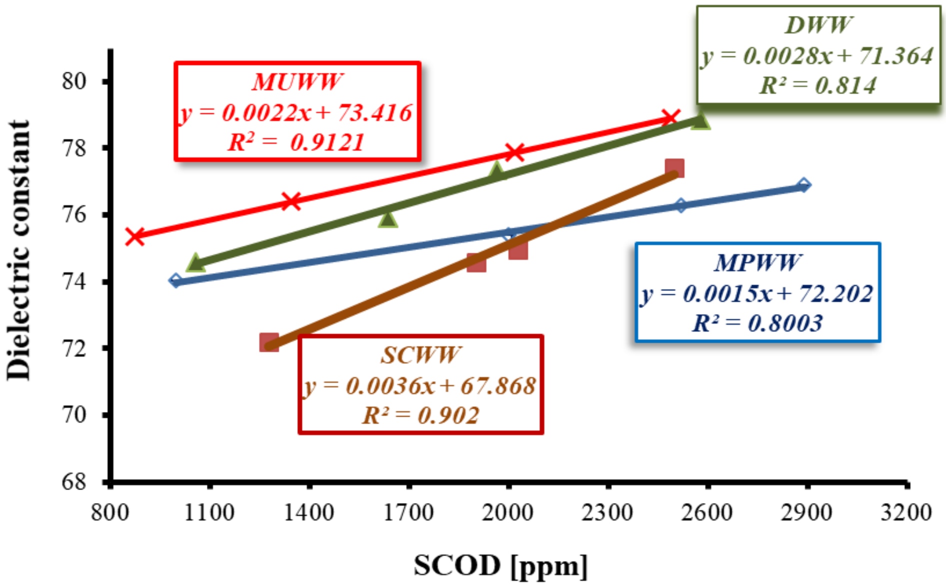

Figure 1. The correlation between SCOD and dielectric constant (f = 2400 MHz, temperature of 20°C)

Microwave irradiation has a strong disintegration effect on solid phase of wastewater (particles), and the macromolecular components are partially degraded due to the thermal effect of microwave irradiation. These effects are manifested in higher organic matter solubility. With the decreasing of molecular weight of wastewater components, and the disintegration of particles the polarization ability of electromagnetic field is improved, which can be detectable by the change of dielectric constant [3, 9].

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In order to verify our hypothesis, that the biodegradability of wastewater has a correlation with organic matter solubility the 5 days biochemical oxygen demand (BOD_5) is also determined. The BOD measures the organic matter content of wastewater what is directly accessible for aerobic decomposing microorganisms. To make easily comparable the change of aerobic biodegradability of different types of wastewater the ration of BOD to SCOD was calculated.
The results show, that dielectric constant determined at 2400 MHz frequency show strong positive linear correlation with BOD5/SCOD parameter (Figure 2). It can be concluded that the type of correlation is independent from the type of wastewater, but the slope and intercept of regression equation is influenced by the origin of wastewater samples.

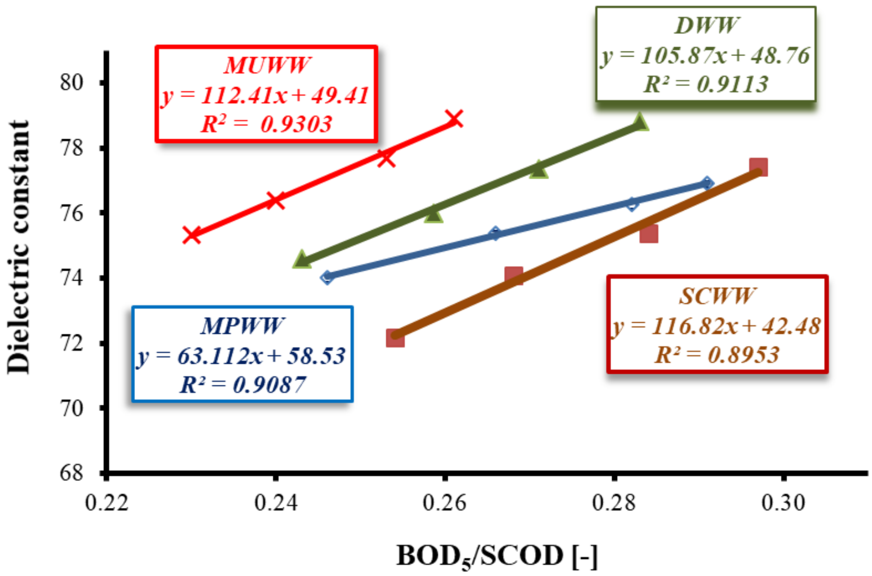

Figure 2. The correlation between BOD_5/SCOD and dielectric constant (f = 2400 MHz, temperature of 20°C)

4. CONCLUSION

Our research focused on the investigation of the applicability of dielectric measurements to detect the change of organic matter solubility and biodegradability of different originated wastewater. Although the dielectric parameters are not suitable to identify the type of wastewater, but the dielectric constant has a good linear correlation with the concentration of soluble organic matters (SCOD) and the aerobic biodegradability indicator (BOD5/SCOD). These preliminary results enable to develop a fast detection method based on the measurement of dielectric parameters for estimate the efficiency of wastewater purification techniques or sludge treatment processes, respectively.

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